U.S. DEPARTMENT OF COMMERCE
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# Nutrient-Algal Relationships in Lake Lillinonah, Danbury, Connecticut, June-September, 1975

National Enforcement Investigations Center, Denver, Colo

Prepared for

Environmental Protection Agency, Boston, Mass Region 1

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Lake Lillinonah is an impoundment of the Housatonic River in western Connecticut. A study by the National Eutrophication Survey Program of the Environmental Protection Agency in 1972-73 found that reducing phosphorus concentrations in Lake Lillinonah would diminish algal growths. The report assesses water quality and phosphorus removal.

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ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF ENFORCEMENT

# NUTRIENT-ALGAL RELATIONSHIPS IN LAKE LILLINONAH

Danbury, Connecticut

June-September 1975

NATIONAL ENFORCEMENT INVESTIGATIONS CENTER - Denver, Colorado
and
REGION I - Boston, Massachusetts

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# I. INTRODUCTION

Lake Lillinonah is an impoundment of the Housatonic River in western Connecticut [Fig. 1]. The lake is used primarily for power generation but it has the potential for recreation, including an excellent smallmouth bass fishery. Despite good public access, lake recreational resources are limited by summer algal blooms.

A study by the National Eutrophication Survey Program of the Environmental Protection Agency (EPA) in 1972-73 found that reducing phosphorus (P) concentrations in Lake Lillinonah would diminish algal growths.[1] The study concluded that phosphorus is the growth-limiting nutrient in the lake and also identified nutrient point sources. The Danbury Wastewater Treatment Plant (WWTP) contributed more than 30% of the phosphorus load to the lake. Consequently, in December 1974, the state issued NPDES Permit No. CT0100145 requiring the Danbury Plant to remove phosphorus to correct water quality deficiencies [App. A, paragraphs 16 and 17].

To assess the impact on Lake Lillinonah of nutrient removal at the Danbury WWTP, EPA-Region I requested that the National Enforcement Investigations Center (NEIC) provide technical assistance to the State of Connecticut. The specific study objectives were:

1. Assess water quality conditions in Lake Lillinonah
2. Determine the algal growth-limiting nutrient and critical nutrient levels for algal growth in Lake Lillinonah
3. Measure the biostimulation characteristics of the Danbury, Connecticut WWTP discharge and its effects on Lake Lillinonah
4. Determine the effects of phosphorus removal from the Danbury WWTP discharge on algal growth in Lake Lillinonah.

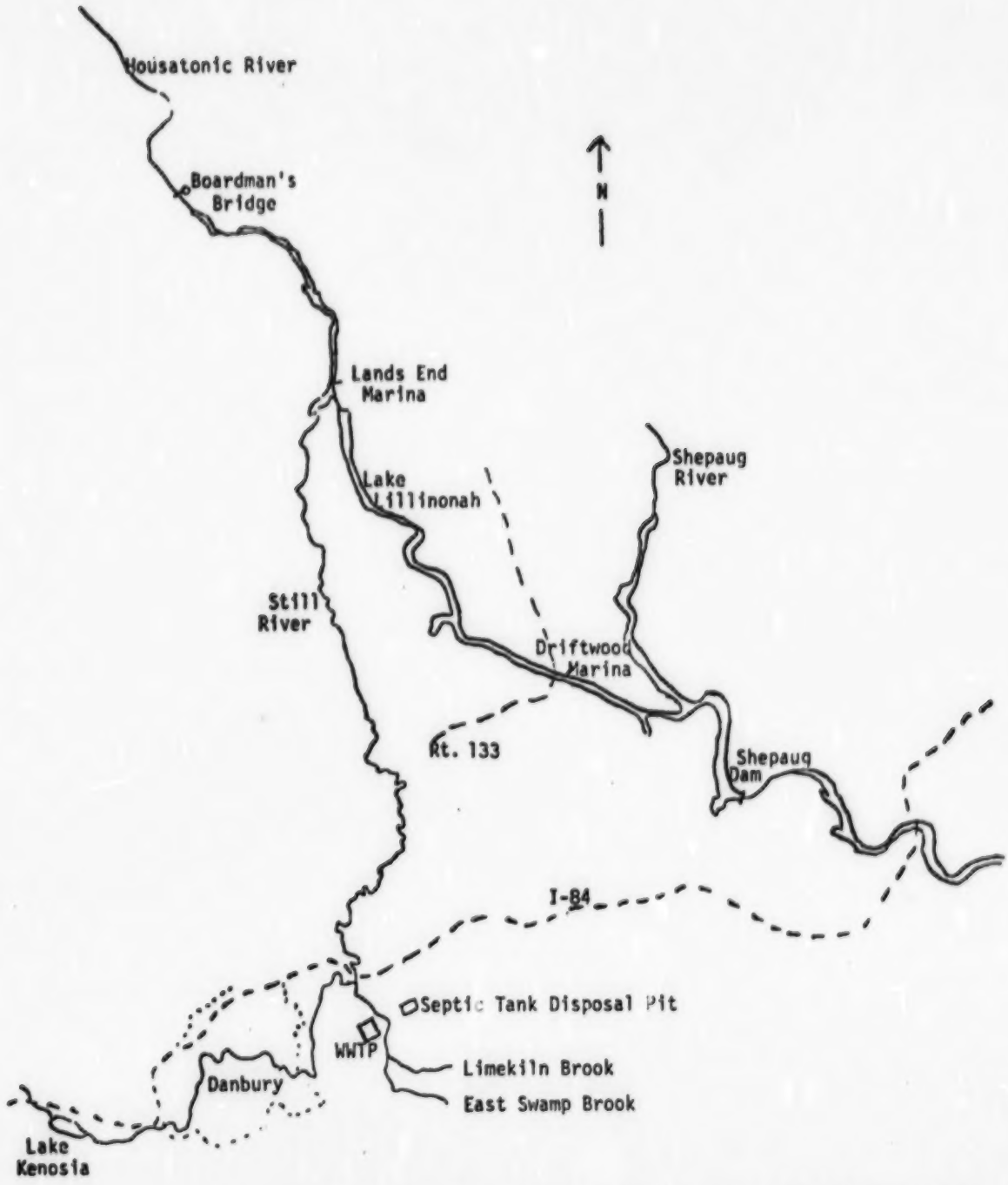


Figure 1. Map of the Danbury, Connecticut - Lake Lillinonah Area

(Not to Scale)

## II. CONCLUSIONS AND RECOMMENDATION

1. An algal bloom blanketed the surface of Lake Lillinonah during the summer of 1975. The bloom was composed primarily of filamentous blue-green algae, *Aphanizomenon* and *Anabaena*.

2. Field and laboratory tests demonstrated that reductions in phosphorus concentrations would diminish algal growths in Lake Lillinonah; each 1 µg/l phosphorus reduction in the lake would result in a corresponding decrease of 0.02 mg/l of blue-green algae.

3. Danbury Wastewater Treatment Plant effluent stimulated algal growth when mixed with water simulated to represent Lake Lillinonah.

4. Removing 95% of the phosphorus at the Danbury Wastewater Treatment Plant would reduce Lake Lillinonah algal growths by at least 29%.

Based on the study results, the following recommendation is made: Implement NPDES Permit No. CT0100145, paragraphs 16 and 17, which require phosphorus removal at the Danbury Wastewater Treatment Plant.

## III. STUDY DESCRIPTION

The Housatonic River enters western Connecticut from Massachusetts and flows south by southeast to Long Island Sound. Lake Lillinonah is the first of three run-of-the-river reservoirs in Connecticut. Formed by construction of the Shepaug Hydroelectric Dam in 1955, the lake includes backwaters on the Housatonic, Still and Shepaug Rivers. The lake winds through steep forested valleys which limit shoreline development. The Housatonic River arm of the lake is approximately 16 km long and 1/2-1 km wide with a surface area of about 800 hectares. The upstream limit of this arm is near the confluence of the Still and Housatonic Rivers [Fig. 1].

The NEIC conducted a three-phase study to assess the impact of wastewater discharges from the Danbury WWTP upon nutrient-algal relationships in a portion of the Lake Lillinonah watershed [Fig. 2].

In June and August 1975, water samples collected from the Housatonic and Still Rivers (Stations 11, 12, 14, 15) and wastewater samples collected from the Danbury WWTP (Station 10) were analyzed for nutrient content and used in laboratory biostimulation tests.

In July 1975 a field study was conducted. In Lake Lillinonah, Secchi depth, sediment oxygen demand (SOD), and dissolved oxygen (DO) were measured at selected stations [App. B, Table 1]. Water and sediment samples were collected from all lake stations for nutrient analyses. Primary productivity studies and *in situ* algal assays were conducted in Lake Lillinonah (Station 5) to determine the rate of algal growth, and to verify laboratory biostimulation test results. Water and wastewater samples were collected for algal assays as described previously except the actual test was *in situ*. Methods for the entire study are presented in Appendix C.

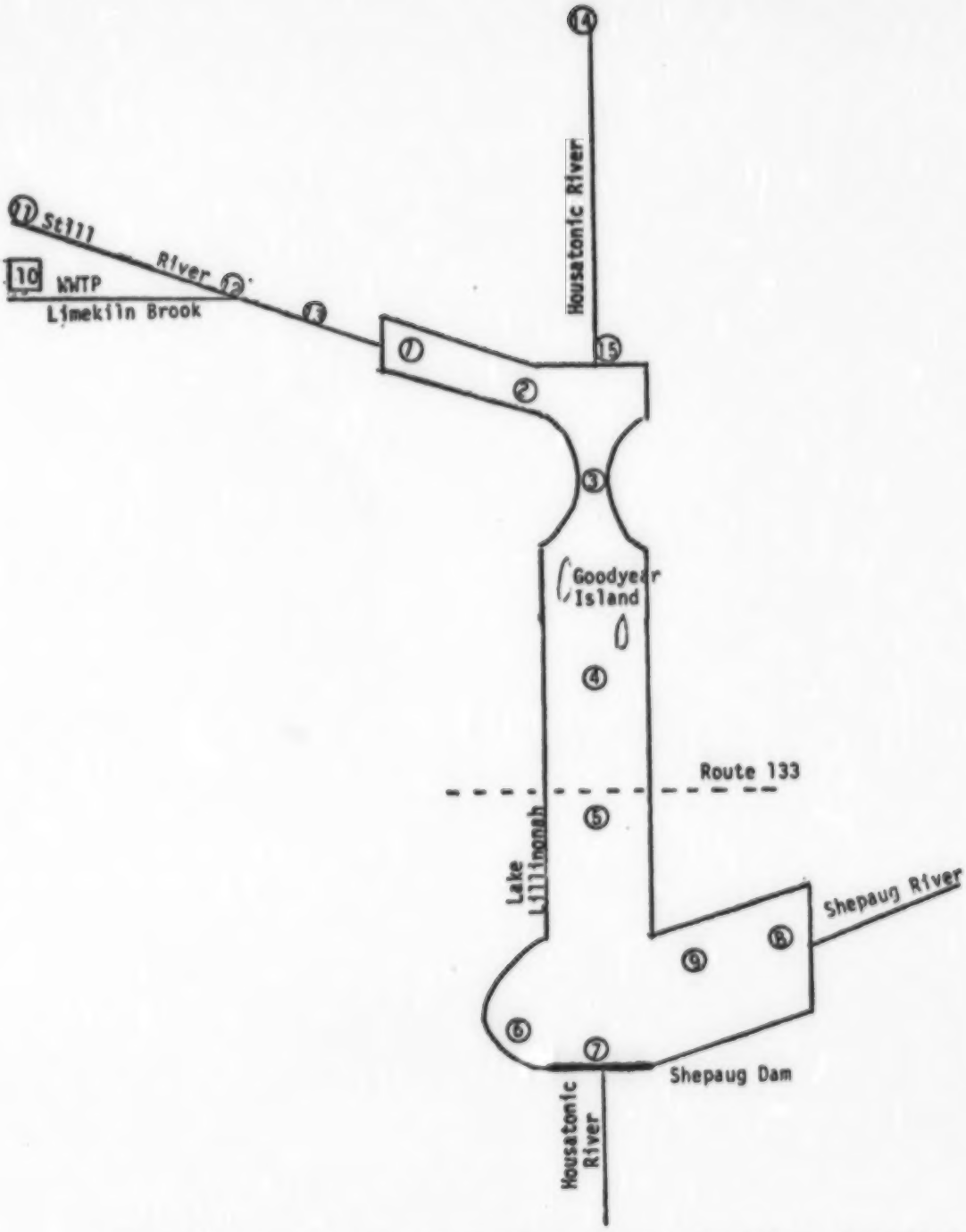


Figure 2. Schematic diagram of sampling locations in the Danbury, Connecticut - Lake Lillinonah Area

## IV. RESULTS AND DISCUSSION

The algal bloom that blanketed the surface of Lake Lillinonah during the summer of 1975 was composed of filamentous blue-green algae, *Aphanizomenon* and *Anabaena*. Primary productivity tests revealed that the algae grew profusely at the rate of 1,511 mg Carbon/$m^2$/day in the top 4 meters of the lake. The algae appeared to be uniformly dense to a depth of 6-8 meters. This dense growth reduced water clarity and caused major fluctuations in the dissolved oxygen concentrations in Lake Lillinonah. Secchi depth ranged from 0.6 to 2.3 meters [App. B, Table 2]. Dissolved oxygen ranged from 4.0 to 17.6 mg/l; usually the lowest concentrations occurred near the lake bottom [App. B, Table 3]. The SOD rate was 1.4 g Oxygen/$m^2$/day inferring that the decrease in oxygen with lake depth was related to algal productivity, particularly respiration and decomposition, in addition to SOD. Study results indicated that a reduction in the algal population would subsequently improve the environmental conditions in Lake Lillinonah.

Water and sediment samples collected at 9 stations in Lake Lillinonah were analyzed for nutrient content. Results showed that the nutrient concentrations in the water and sediment were highest in the upper end of the reservoir near the confluence of the Housatonic and Still Rivers [App. B, Table 4]. Additional nutrient studies at the mouths of these lake tributaries showed that the Still River contributed an average concentration of 2.4 mg/l nitrogen and 0.9 mg/l phosphorus. This was approximately 9 times the average concentration of nitrogen and 4 times the average concentration of phosphorus contributed by the Housatonic River [App. B, Table 5]. Reportedly, the major source of nutrients in the Still River was the Danbury WWTP.[1]

Algal assays were conducted in June, July and August 1975 to determine the significance of the Danbury WWTP discharge as a nutrient source. As described in Methods [App. C] Lake Lillinonah water was simulated in the laboratory by proportionally mixing water from the Housatonic River (Stations 14 and 15) with water from the Still River (Stations 11 and 12). Algal assay tests showed that this lake water stimulated only minor growth of test algae *Selenastrum* and *Anabaena*. The *in situ* tests were the most extensive and a summary of this data is presented in Appendix B, Table 6.

To determine if nitrogen or phosphorus was the growth-limiting nutrient, various concentrations of these nutrients were added to simulated lake water. Assays using green and blue-green test algae responded to the nutrient additions differently. In the June and July tests with the green algae *Selenastrum*, nitrogen additions stimulated algal growth; in August, phosphorus additions were found to stimulate algal growth. Phosphorus additions stimulated algal growth in all tests with the blue-green alga *Anabaena*.* Therefore, phosphorus was the growth-limiting nutrient in all tests with *Anabaena* and in August tests with *Selenastrum*. The *in situ* tests were the most extensive and a summary of this data is presented in Appendix B, Table 7.

As discussed earlier, the algal bloom in Lake Lillinonah was composed largely of blue-green algae and subsequent algal assays demonstrated that phosphorus must be limited to control blue-green algal growth. The algal assays also indicated that each reduction of 1.0 µg/l of phosphorus resulted in a corresponding reduction of 0.02 mg/l dry weight of blue-green algae.

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* *Some blue-green algae including Anabaena and Aphanizomenon are capable of using atmospheric nitrogen as a nutrient source.*

Biostimulatory characteristics of the Danbury WWTP effluent were evaluated from the results of another series of algal assays. Effluent from the DAnbury WWTP was serially diluted with stimulated lake water and the mixtures were inoculated with algal cells. The effluent and lake water mixture stimulated an algal bloom. On a maximum dry-weight basis algal growth increased an average of 482% when compared to growth in lake water without the effluent addition [App. B, Table 7].

In a final series of laboratory tests, the Danbury WWTP effluent was treated with calcium hydroxide, $Ca(OH)_2$, which precipitated (removed) an average of 96% of the phosphorus [App. B, Table 8]. The treated effluent was added to lake water containing test algae. Results showed that the treated effluent stimulated 90% less algal growth than the phosphorus-rich effluent that was being discharged by the Danbury WWTP [App. B, Table 7].

The State of Connecticut has developed a Housatonic River Basin Model that can be used to show the relationship of nutrient removal at the Danbury WWTP to the reduction of nutrients in Lake Lillinonah.[2] According to model predictions and laboratory test results described herein, the removal of 96% of the phosphorus from the Danbury WWTP effluent would result in a phosphorus contribution into Lake Lillinonah of between 0.01 and 0.02 mg/l from the Still River. Therefore 96% phosphorus removal at the Danbury WWTP will ultimately reduce algal growth in Lake Lillinonah by at least 29%. For minimum algal problems nutrient levels should not exceed 0.30 mg/l inorganic nitrogen and 0.01 mg/l ortho phosphorus.[3] However, any reductions in Lake Lillinonah phosphorus concentration will result in reductions in algal growths.

## ASSOCIATED STUDY OBSERVATIONS

Nutrient studies were conducted in the Still River watershed near the Danbury WWTP to obtain supplemental information concerning nitrogen

and phosphorus sources. Results showed that the Still River at Eagle Road (Station 12) had nutrient concentrations of 1.4 mg/l inorganic N, 0.7 mg/l total P. Upstream concentrations for the Still River at Lake Kenosia were much lower (0.02 mg/l inorganic N, 0.15 mg/l total P) [App. B. Table 5]. The only known nutrient source between the two stations is Sympaug Brook which carries wastes from the Bethel WWTP. Reportedly, this plant contributes less than 2% of the annual phosphorus load to Lake Lillinonah.[1] Increases in nutrient concentrations were observed downstream from the Danbury WWTP to Station 4 in the headwaters of Lake Lillinonah. Because concentrations at the Dump Road 0.1 km downstream from the Danbury WWTP were higher than concentrations in the effluent other potential nutrient sources at the Danbury WWTP and Septic Tank Disposal Pit were sampled [App. B, Table 9). A leak from the grit chamber at the Danbury WWTP was sampled and found to contain 10.4 mg/l inorganic N and 19 mg/l total P. The plant is under State order to eliminate this unpermitted discharge. Nutrient concentrations in this discharge were sometimes higher than in the influent. This discharge accounts for only part of the increased nutrient concentrations at the Dump Road. The concentrated wastes of the septic tank disposal pit contained 130 mg/l inorganic N and 185 mg/l total P. The septic tank disposal pit is located in the sanitary landfill and has no discrete discharge. The area is swampy and located within 1 km of the Danbury WWTP [Fig. 1].

# APPENDIX A

## NPDES PERMIT NO. CT0100145

## FOR DANBURY WASTEWATER TREATMENT PLANT DISCHARGE 001

# STATE OF CONNECTICUT
## DEPARTMENT OF ENVIRONMENTAL PROTECTION

STATE OFFICE BUILDING HARTFORD, CONNECTICUT 06115

WATER COMPLIANCE AND HAZARDOUS SUBSTANCES
DIVISION OF ENVIRONMENTAL QUALITY
CONNECTICUT DEPARTMENT OF ENVIRONMENTAL PROTECTION
STATE OFFICE BUILDING - ROOM 129
HARTFORD, CONNECTICUT 06115

NPDES PERMIT

City of Danbury
City Hall
174 Main Street
Danbury, Connecticut 06810

Attention: Mr. Charles Ducibella
Mayor

Re: DEP/WPC 034-S01
City of Danbury
Still River Watershed

Gentlemen:

This order is authorized to be issued by Chapter 474a, Connecticut General Statutes and Section 402(b), Federal Water Pollution Control Act Amendments of 1972, 86 Stat. 816 et. seq., and pursuant to an approval dated September 26, 1973, by the Administrator of the United States Environmental Protection Agency for the State of Connecticut to administer an N.P.D.E.S. permit program.

Your application, filed with the Connecticut Department of Environmental Protection on May 11, 1973 has been reviewed by the Connecticut Department of Environmental Protection.

The Director, Water Compliance and Hazardous Substances Division, Department of Environmental Protection (hereinafter "the Director") hereby finds that the City of Danbury is maintaining a facility described in the above referenced application which no longer insures or adequately protects against pollution of the waters of the state under the provisions of Chapter 474a of the Connecticut General Statutes.

The Director, acting under Section 25-54j hereby orders the City of Danbury to take such action as is necessary to:

1) Insure that all wastewaters described in the above referenced application are collected, treated and discharged in accordance with the

plans and specifications approved by the Director on March 4, 1970 together with associated engineering documents, correspondence and other data submitted to comply or obtained to verify compliance with Order No. 7 entered on May 15, 1967 and/or discharged in accordance with this order.

2) Insure that all discharges described in this order shall not exceed and shall otherwise conform to the specific terms and general conditions specified herein.

A) Discharge Serial No. 001 (Effluent)
Receiving Stream - East Swamp Brook
Average Daily Flow - 12,500,000 gallons per day

Before September 30, 1977

| Parameter | Monthly Average Quantity | Monthly Average Concentration | Minimum Percentage Removal Efficiency |
|---|---|---|---|
| Biochemical Oxygen Demand | 1419.4 kg/day | 30 mg/l | 85% |
| Suspended Solids | 1419.4 kg/day | 30 mg/l | 85% |

1) The discharge shall be required to meet the more stringent of the monthly average concentration or minimum removal efficiency requirements for each parameter.

2) The monthly average quantities and monthly average concentrations specified above shall not be exceeded by a factor of 1.5 during any week.

3) The pH of the discharge shall not be less than 6.5 nor greater than 8.0 at any time.

4) The discharge shall not contain a visible oil sheen, foam or floating solids.

5) The discharge shall not contain more than 0.1 milliliters per liter settleable solids.

6) The discharge shall not cause visible discoloration of the receiving waters.

7) The total chlorine residual of the effluent shall not be less than 0.5 mg/l nor greater than 3.0 at any time.

8) The geometric mean of the total coliform bacterial values for the effluent samples collected in a period of 30 consecutive days shall not exceed 1000 per 100 milliliters The geometric mean of these values for effluent samples collected in a period of seven consecutive days shall not exceed 2000 per 100 milliliters.

After September 30, 1977

In conformance with the criteria to be established in the engineering report required by paragraph F.

3) Not discharge any new pollutant not authorized by this order which has or may have an adverse impact on the receiving waters.

4) Monitor and record the following for the purpose of reporting quality and quantity of each discharge according to the following schedule:

A) Influent

| Parameter | Minimum Frequency of Sampling | Sample Type |
|---|---|---|
| Biochemical Oxygen Demand$_5$ | Twelve per Month | Composite |
| Suspended Solids | Twelve per Month | Composite |
| Temperature | Twenty per Month | Grab |
| pH | Twenty per Month | Grab |
| Settleable Solids | Twenty per Month | Grab |
| Total Phosphorus | One per Month | Composite |
| Organic Nitrogen as N | One per Month | Composite |
| Ammonia Nitrogen as N | One per Month | Composite |
| Nitrite-Nitrate as N | One per Month | Composite |

a) Record the total flow during the period of composite sample collection and the instantaneous flow at the time of each aliquot sample collection, and the instantaneous flow at the time of grab sample collection.

b) Any grab sample or composite sample required to be taken less frequently than daily shall be taken during the period of Monday through Friday inclusive. Composite samples and grab samples shall be taken between 6 a.m. and 6 p.m.

B) Discharge Serial No. 001 (Effluent)

| Parameter | Minimum Frequency of Sampling | Sample Type |
|---|---|---|
| Biochemical Oxygen Demand$_5$ | Twelve per Month | Composite |
| Suspended Solids | Twelve per Month | Composite |
| Chlorine Residual | Four per Working Day | Grab |
| Total Coliform | Four per Month | Grab |
| Dissolved Oxygen | Twenty per Month | Grab |
| Temperature | Twenty per Month | Grab |
| pH | Twenty per Month | Grab |
| Turbidity | Twenty per Month | Grab |
| Settleable Solids | Twenty per Month | Grab |
| Total Phosphate as P | One per Month | Composite |
| Organic Nitrogen as N | One per Month | Composite |
| Ammonia Nitrogen as N | One per Month | Composite |
| Nitrite-Nitrate as N | One per Month | Composite |

a) Record and report on a daily basis the minimum, maximum and total flow of the discharge.

b) Record the total flow during the period of composite sample collection and the instantaneous flow at the time of each aliquot sample collection, and the instantaneous flow at the time of grab sample collection.

c) Any grab sample or composite sample required to be taken less frequently than daily shall be taken during the period of Monday through Friday inclusive. Composites and grab samples shall be taken between 6 a.m. and 6 p.m.

5) Monitor and record the following operational parameter according to the following schedule:

| Parameter | Location | Minimum Frequency of Sampling | Sample Type |
|---|---|---|---|
| Temperature | Each Digestion Unit | Weekly | Grab |
| Alkalinity | Each Digestion Unit | Weekly | Grab |
| Volatile Acids | Each Digestion Unit | Weekly | Grab |
| pH | Each Digestion Unit | Weekly | Grab |

A) Record the gallons of septage discharged to the treatment facility for the month.

B) Record the pounds of dry solids discharged to and removed from the solids handling system on a monthly basis.

C) Record the chlorine dosages in pounds and mg/l on a daily basis.

D) Record the percentage of recycled flow on a daily basis.

E) Record the volume of digester gas produced on a monthly basis.

6) Not bypass the treatment facilities at any time except as may be authorized in Section 2 of this order and/or under emergency conditions.

The Water Compliance Unit Sewerage Facilities Services Section, (Telephone No. 566-2409 or 566-2373) shall be notified during normal working hours, Monday through Friday 8:30 a.m. to 4:30 p.m. and in writing within 72 hours, of each occurrence of an emergency diversion or bypass of untreated or partially treated sewage, or failure of any major component of the treatment facilities which would reduce the quality of the effluent. The written report shall contain:

a) The cause of the diversion or bypass or treatment component failure.

b) The time the incident occurred and the anticipated time which it is expected to continue or, if the condition has been corrected, the duration.

c) The steps being taken to reduce and minimize the effect on the receiving waters.

d) The steps that will be taken to prevent reoccurrence of the condition in the future.

7) Dispose of screenings, sludges and other solids or oils and other liquid chemicals at locations approved in accordance with the provisions of Chapter 474a and/or Chapter 361a of the Connecticut General Statutes or to waste haulers licensed under Chapter 474a of the Connecticut General Statutes.

8) Provide an alternate power source and/or such other means as may be appropriate to adequately operate the wastewater treatment facility and/or pumping stations to insure that no discharge of untreated wastewater will occur during a failure of the primary power source.

9) No new dishcarge from a single source to the sewage system of: 1) domestic sewage in excess of 5,000 gallons per day; 2) industrial wastewaters; and/or 3) cooling waters may be authorized without the discharger first obtaining a permit from the Director.

10) On or before April 10, 1975 and monthly thereafter, submit to the Director a listing of all new discharges authorized to be connected to the wastewater collection system.

11) On or before March 31, 1975 submit for the review and approval of the Director a Sewer Ordinance regulating discharges to the wastewater collection system.

12) On or before March 31, 1975 verify to the Director that compliance with paragraph 1 is being achieved and that the provisions of paragraphs 2, 3, 4, 5, 6, 7, 8 and 9 will be complied with.

13) On or before March 31, 1975 submit for the review and approval of the Director a report detailing the existing or proposed system of achieving compliance with the terms of paragraph 8 including if appropriate a time schedule for: 1) the submission of plans and/or specifications, 2) the start of construction, and 3) the placing of the system in operation.

14) On or before August 10, 1975 and before the 10th of each month thereafter, submit to the Director all detailed monitoring data required under the provisions of paragraphs 4 and 5 above.

15) On or before September 30, 1975 verify to the Director that all construction required by paragraph 8 above has been completed.

16) Install alterations and/or additions to the existing wastewater treatment facility to provide the level of treatment necessary to correct water quality deficiencies in East Swamp Brook, the Still River and Housatonic River giving special attention to the removal of additional carbonaceous and nitrogenous biochemical oxygen demand, and phosphorous. The specific loading allocations to be considered in the design of such additional

treatment facilities will be established at the pre-report conference and confirmed in the engineering report.

17) Install temporary alterations and/or additions to the existing wastewater treatment facility and modifications to the operational procedures as may be practical to provide for the removal of phosphorous until such time as the requirements of paragraph 16 above are accomplished.

The above described specific terms may be revised following public notice and public hearing, if required, and/or on the basis of a detailed engineering study if agreed to by the Director.

The City of Danbury is further ordered to accomplish the above described program, except as may be revised by agreement reached at or following the pre-report conference required by Section 25-54v of the Connecticut General Statutes or as amended by the recommendations of a detailed engineering study and agreed to by the Director in accordance with the following schedule:

A) On or before April 30, 1975 submit for the review and approval of the Director a report describing such alterations/additions in staffing and operating procedures as may be required to assure compliance with the specific terms of this order.

B) On or before July 31, 1975 verify to the Director that such procedures have been placed in operation.

C) On or before July 31, 1975 verify to the Director that such additional manpower necessary to assure compliance with the specific terms of this order has been employed.

D) On or before May 31, 1975 submit for the review and approval of the Director an engineering report containing an inflow-infiltration analysis of the wastewater collection system prepared in accordance with the requirements of 40 C.F.R. § 35.927 (39 Federal Register 5262).

E) On or before September 30, 1976, if deemed necessary by the Director as a result paragraph D above, submit for the review and approval of the Director an engineering report containing a inflow-infiltration evaluation prepared in accordance with 40 C.F.R. § 35.927 (39 Federal Register 5262).

F) On or before June 30, 1975 submit for the review and approval of the Director an engineering report addressing the requirements of paragraph 16 above prepared in accordance with § 25-54v which shall include a current detailed cost estimate of the eligible construction work.

G) On or before June 30, 1975 submit for the review and approval of the Director contract plans and specifications with a summary basis of design for alterations and/or additions as may be required to comply with paragraph 17 above.

H) On or before October 31, 1975 verify that the construction of the alterations and/or additions to the existing waste-water treatment facility and modifications to the operational procedures required to comply with paragraph 17 above has been completed.

I) On or before January 31, 1976 submit for the review and approval of the Director contract plans and specifications for the alterations and/or additions required to comply with paragraph 16 above.

J) On or before February 29, 1976 verify to the Director that all the necessary local financing for the alterations and/or additions required to comply with paragraph 16 above has been completed.

K) On or before April 30, 1976 verify to the Director that advertising for bids for the alterations and/or additions required to comply with paragraph 16 above has been completed.

L) On or before June 30, 1976 verify to the Director that construction of the alterations and/or additions required to comply with paragraph 16 above has been started.

M) On or before September 30, 1977 verify to the Director aht the constructed facilities have been placed in operation.

This order shall be considered as the permit required by Section 402 of the Federal Water Pollution Control Act and shall expire on December 30, 1979.

This order shall be subject to all the NPDES General Conditions dated December 27, 1974 which are hereby incorporated into this order.

Upon verification of full compliance with this order, a letter acknowledging this order to be equivalent of a permit issued under section 25-54i and/or a revised NPDES permit will be issued.

Entered as an order of the Director the 30 th day of December, 1974.

Robert B. Taylor

Robert B. Taylor, DIRECTOR
WATER COMPLIANCE AND HAZARDOUS SUBSTANCES
Department of Environmental Protection
State of Connecticut

Order No. 1726
NPDES No. CT0100145

# APPENDIX B
# STUDY FINDINGS
# TABLES 1-9

*Table 1*

*SAMPLING PARAMETERS AND STATION LOCATIONS*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*
*July 1975*

| Station Number | Location | Parameters Measured | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Nutrients | | | Primary Production | Sediment Oxygen Demand | Dissolved Oxygen | Secchi Depth |
| | | Surface Water | Bottom Water | Sediment | | | | |
| | Lake Lillinonah | | | | | | | |
| 1 | Still River 0.2 km upstream from mouth | | X | X | | | | X |
| 2 | Still River at mouth | | X | X | | | X | X |
| 3 | Housatonic River at Lanesville Road | | X | X | | | X | X |
| 4 | Housatonic River at first island downstream from Goodyear Island | | X | X | | | X | X |
| 5 | Housatonic River at Route 133 | X | X | X | X | X | X | X |
| 6 | Housatonic River at cove near Shepaug Dam | | X | X | | | X | X |
| 7 | Housatonic River upstream from Shepaug Dam | | X | X | | | X | X |
| 8 | Shepaug River 1.0 km upstream from mouth | | X | X | | | | X |
| 9 | Shepaug River at mouth | | X | X | | | X | X |
| | Nutrient Sources | | | | | | | |
| 10 | Danbury WWTP Effluent | X | | | | | | |
| | Housatonic and Still Rivers | | | | | | | |
| 11 | Still River at Lake Kenosia | X | | | | | | |
| 12 | Still River at Eagle Road | X | | | | | | |
| 13 | Still River at Lanesville Road | X | | | | | | |
| 14 | Housatonic River at Boardman's Bridge | X | | | | | | |
| 15 | Housatonic River at Lands End Marina | X | X | X | | | | X |

*Table 2*

*SECCHI DEPTH OF RECEIVING WATER*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*
*July 1975*

| Station Number | Location | Secchi Depth (meters) |
|---|---|---|
| 1 | Still River 0.2 km upstream from mouth | 0.6 |
| 2 | Still River at mouth | 0.7 |
| 3 | Housatonic River at Lanesville Bridge | 1.0 |
| 4 | Housatonic River at first island downstream from Goodyear Island | 2.0 |
| 5 | Housatonic River at Route 133 | 2.3 |
| 6 | Housatonic River at cove near Shepaug Dam | 1.9 |
| 7 | Housatonic River upstream from Shepaug Dam | 2.0 |
| 8 | Shepaug River 1.0 km upstream from mouth | 2.0 |
| 9 | Shepaug River at mouth | 2.1 |
| 15 | Housatonic River at Lands End Marina | 1.0 |

*Table 3*

*RECEIVING WATER DISSOLVED OXYGEN PROFILES*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*
*July 1975*

| Station Number | Location | Depth (meters) | Temperature (°C) | Dissolved Oxygen (mg/l) | Saturation (%) |
|---|---|---|---|---|---|
| 2 | Still River at mouth | Surface | 26.5 | 6.3 | 77 |
| | | 2 | 25.0 | 8.3 | 99 |
| 3 | Housatonic River at Lanesville Bridge | Surface | 25.0 | 9.5 | 113 |
| | | 3.5 | 25.0 | 9.1 | 108 |
| | | 7 | 24.5 | 9.2 | 109 |
| 4 | Housatonic River at first island downstream from Goodyear Is. | Surface | 27.0 | 17.6 | 217 |
| | | 3 | 26.0 | 9.2 | 112 |
| | | 6 | 25.0 | 6.4 | 76 |
| 5 | Housatonic River at Route 133 | Surface | 27.5 | 14.9 | 186 |
| | | 2 | 26.5 | 10.5 | 128 |
| | | 4 | 25.5 | 8.4 | 101 |
| | | 14 | 23.0 | 7.0 | 80 |
| 7 | Housatonic River upstream from Shepaug Dam | Surface | 29.5 | 16.0 | 208 |
| | | 10 | 23.5 | 6.8 | 79 |
| | | 20 | 22.5 | 6.9 | 78 |
| | | 28 | 22.0 | 5.4 | 61 |
| 9 | Shepaug River at mouth | Surface | 28.0 | 14.8 | 187 |
| | | 3 | 25.5 | 8.3 | 100 |
| | | 6 | 23.5 | 4.0 | 47 |
| 15 | Housatonic River at Lands End Marina | Surface | 25.0 | 9.6 | 114 |
| | | 2 | 24.5 | 8.8 | 105 |
| | | 4 | 24.5 | 11.4 | 136 |

*Table 4*

*NUTRIENT ANALYSES OF WATER AND SEDIMENTS*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*
*July 1975*

| Station Number | Location | Water | | Sediment |
|---|---|---|---|---|
| | | Inorganic N (mg/l) | Total P (mg/l) | Total P (mg/g) |
| 1 | Still River 0.2 km upstream from mouth | 1.9 | 8.8 | 2.3 |
| 2 | Still River at mouth | 1.3 | 2.2 | 1.2 |
| 3 | Housatonic River at Lanesville Road | 0.71 | 3.6 | 1.4 |
| 4 | Housatonic River at first island downstream from Goodyear Island | 0.15 | 0.24 | 1.8 |
| 5 | Housatonic River at Route 133 | 0.49 | 1.6 | 1.4 |
| 6 | Housatonic River at cove near Shepaug Dam | 0.48 | 1.1 | 2.9 |
| 7 | Housatonic River upstream from Shepaug Dam | 0.43 | 1.6 | 1.8 |
| 8 | Shepaug River 1.0 km from mouth | 0.33 | 1.8 | 0.9 |
| 9 | Shepaug River at mouth | 0.37 | 1.6 | 1.3 |
| 15 | Housatonic River at Lands End Marina | 0.55 | 1.5 | 0.8 |

*Table 5*

*NUTRIENT ANALYSES OF WASTE AND RECEIVING WATERS*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*

| Station Number | Location | Inorganic N (mg/l) | | | | Total P (mg/l) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | June | July | August | Average | June | July | August | Average |
| 10 | Danbury WWTP effluent | 14.2 | 8.9 | 11.1 | 11.4 | 8.8 | 7.2 | 6.9 | 7.6 |
| 11 | Still River at Lake Kenosia | | <0.02 | 0.02 | 0.02 | | 0.15 | 0.15 | 0.15 |
| 12 | Still River at Eagle Road | 1.4 | 0.71 | 2.0 | 1.4 | 0.56 | 0.54 | 1.1 | 0.73 |
| 13 | Still River at Lanesville Road | 3.0 | 1.1 | 3.0 | 2.4 | 0.30 | 0.90 | 1.6 | 0.93 |
| 14 | Housatonic River at Boardman's Bridge | 0.05 | <0.32 | 0.37 | 0.25 | 0.17 | 0.47 | 0.29 | 0.31 |
| 15 | Housatonic River at Lands End Marina | <0.20 | <0.36 | <0.27 | 0.28 | 0.10 | 0.39 | 0.19 | 0.23 |
| 5 | Housatonic River at Route 133 | <0.03 | <0.02 | 0.38 | 0.14 | 0.25 | 0.23 | 0.18 | 0.22 |

*Table 6*

*IN SITU ALGAL GROWTH POTENTIAL TESTS - NUTRIENT ADDITIONS*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*
*July 1975*

| Addition (mg/l) | Inorganic N (mg/l) | Total P (mg/l) | Maximum yield (mg/l-dry wt) Selenastrum | Anabaena |
|---|---|---|---|---|
| Control (100% simulated Lake Water) | 0.32 | 0.17 | 21.2 | 16.2 |
| 0.3N | 0.62 | 0.17 | 22.7 | 15.4 |
| 1.0N | 1.32 | 0.17 | 24.3 | 17.8 |
| 3.0N | 3.32 | 0.17 | 23.7 | 16.7 |
| 10N | 10.32 | 0.17 | 21.6 | 15.2 |
| 0.03P | 0.32 | 0.20 | 21.0 | 19.9 |
| 0.1P | 0.32 | 0.27 | 20.0 | 20.5 |
| 0.3P | 0.32 | 0.57 | 20.0 | 29.1 |
| 1.0P | 0.32 | 1.17 | 20.5 | 24.6 |
| 1.0N, 0.1P | 1.32 | 0.27 | 47.9 | 45.4 |
| 3.0N, 0.3P | 3.32 | 0.47 | 71.8 | 73.3 |

*Table 7*

*ALGAL GROWTH POTENTIAL TESTS - EFFLUENT ADDITIONS*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*
*July 1975*

| Addition (%) | Inorganic N (mg/l) | | Total P (mg/l) | | Maximum yield† | |
|---|---|---|---|---|---|---|
| | Danbury 001 | Treated | Danbury 001 | Treated | Danbury 001 | Treated†† |
| Control (100% simulated lake water) | 0.32 | | 0.17 | | 21.2 | |
| 0.3 | 0.34 | 0.34 | 0.19 | 0.17 | 22.7 | 19.5 |
| 1.0 | 0.40 | 0.40 | 0.23 | 0.17 | 22.4 | 20.1 |
| 3.0 | 0.57 | 0.57 | 0.35 | 0.18 | 27.8 | 21.4 |
| 10.0 | 1.16 | 1.16 | 0.78 | 0.19 | 42.9 | 23.6 |
| 25.0 | 2.42 | 2.42 | 1.70 | 0.21 | 75.7 | 17.8 |

† *mg/l - dry wt.*
†† *Treated with 400 mg/l* $Ca(OH)_2$

*Table 8*

*NUTRIENT REMOVAL FROM DANBURY WWTP EFFLUENT*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*

| Month (1975) | Total P (mg/l) | | | % Phosphorus Removal | |
|---|---|---|---|---|---|
| | Intake | Effluent | Stripped | Influent | Effluent |
| June | 9.9 | 8.8 | 0.43 | 96.6 | 96.0 |
| July | 20.0 | 7.2 | 0.34 | 98.3 | 95.3 |
| August | 21.0 | 6.9 | 0.19 | 99.1 | 97.2 |

*Table 9*

*NUTRIENT ANALYSES OF WASTE AND RECEIVING WATERS*
*LAKE LILLINONAH - DANBURY, CONNECTICUT*

| Location | Inorganic N (mg/l) | | | | Total P (mg/l) | | | |
|---|---|---|---|---|---|---|---|---|
| | June | July | August | Average | June | July | August | Average |
| Danbury WWTP influent | 9.7 | 10.4 | 17.3 | 12.5 | 9.9 | 20 | 21 | 17 |
| Danbury WWTP bypass (grit chamber leak) | | 10.6 | 10.3 | 10.4 | | 24 | 14 | 19 |
| Danbury septic tank disposal pit | | 110 | 150 | 130 | | 60 | 310 | 185 |
| East Swamp Brook at Meckauer Park | | 0.23 | 0.41 | 0.32 | | 0.27 | 0.09 | 0.18 |
| Limekiln Brook at Meckauer Park | | 0.21 | 0.39 | 0.30 | | 0.22 | 0.37 | 0.30 |
| Limekiln Brook at Dump Road | | 8.5 | 12.3 | 10.4 | | 8.4 | 9.3 | 8.8 |
| Limekiln Brook at Newtown Road | | 3.9 | 7.8 | 5.8 | | 3.3 | 4.9 | 4.1 |
| Housatonic River downstream from Shepaug Dam | 0.40 | 0.41 | 0.58 | 0.46 | 0.05 | 0.24 | 0.19 | 0.16 |

# APPENDIX C
# METHODS

# METHODS

## NUTRIENTS

Nutrient analyses ($NH_3$ - N, $NO_2$ + $NO_3$ - N, ortho and total P) were performed on a Technicon Autoanalyzer using procedures described in EPA *Methods of Chemical Analysis of Water and Wastes.*[4] Nutrient analyses were conducted on all receiving water, effluent, and sediment samples collected during the survey. All samples were collected by grab sampling. Water samples were preserved with mercuric chloride (40 mg/l). All samples for nutrient analyses were labeled, placed in an ice chest, chilled, and transported to NEIC for analyses.

## ALGAL GROWTH POTENTIAL

Algal growth potential (AGP) tests were performed as outlined in *Algal Assay Procedure - Bottle Test*, August 1971.[5] Samples were autoclaved to kill indigenous algae. An inoculum of green algae, *Salenastrum capricornutum*, or blue-green algae, *Anabaena flos-aquae*, (standard test organisms) was added to each test container. Receiving water was a mixture of Housatonic and Still River water collected upstream of major local nutrient sources. The mixture was based on low flow contributions of the Housatonic and Still Rivers to Lake Lillinonah. Standard test conditions (volume, light, temperature, shaking, incubation period) remained constant in each test. Algal growth was measured by *in vivo* fluorescence and gravimetrically. Tests were run *in situ* and in the laboratory. *In situ* tests were made in 1 liter cubitaners in the reservoir under ambient light and temperature conditions. Laboratory tests were

made in 250 ml Erlenmeyer flasks under 24-hour light and constant temperature conditions. The following experimental variables were tested: filtered versus unfiltered receiving water, green versus blue-green algal inoculum, raw versus treated effluent, and effluent versus nutrient additions.

## NUTRIENT REMOVAL

Phosphorus removal was attempted on Danbury WWTP effluent samples. Phosphorus was precipitated by adding hydrated lime (400 mg/l $Ca(OH)_2$) to the sample and shaking it vigorously for two minutes. Next, the effluent was allowed to settle and the supernatant was drawn off. Nutrient analyses were performed at NEIC.

## PRIMARY PRODUCTION

Primary production was measured as outlined in the 13th edition of *Standard Methods for Examination of Water and Wastewaters* (1971).[6] The depth of the euphotic zone (1% light) was determined with a submarine photometer. Light energy received during incubation periods and daily photoperiods were determined with a pyrheliograph. Water samples were collected with a Van Dorn sampler. Five 300-ml bottles were filled with water collected from each depth of the subdivided euphotic zone. Three of these bottles were unaltered and considered light bottles. One of the light bottles was fixed immediately and used to measure initial DO. All light penetration was eliminated from the remaining two bottles. The two light and two dark bottles were suspended in the water at the depth from which the sample was obtained, and after incubation the bottles were fixed immediately and iced in a dark container until titration. Samples were analyzed according to the azide modification of the Winkler Method.[6]

## ALGAL POPULATIONS

To assess algal bloom populations, surface grab water samples were collected and preserved with 5% formalin and examined microscopically at NEIC.

## SEDIMENTS

Sediments and interstitial water samples were collected by scuba divers. Plastic coring tubes were turned into the sediment by hand and capped. The overlying few centimeters of water were preserved as an interstitial water sample and the top few centimeters of sediment were extruded from the tube into a whirlpac. This technique provided an undistrurbed sediment sample. The samples were analyzed for nutrients at NEIC.

## SEDIMENT OXYGEN DEMAND

The sediment oxygen demand (SOD) rate was estimated from changes in the oxygen content of water sealed and stirred *in situ* in a cylindrical chamber constructed of clear plexiglas. The chamber was bolted to an aluminum supporting flange and placed on the lake bottom by scuba divers. The lid was lowered into place and secured. The chamber covered 0.07 $m^2$ of bottom sediments and entrapped 20.5 l of water over the sediments. Water was circulated in the chamber by the submersible stirrer for the dissolved oxygen probe. The dissolved oxygen content of the entrapped water was monitored with a portable dissolved oxygen meter. A port in the lid allowed salt to be injected into the system to raise the specific conductance. Samples were withdrawn through this port and the conductivity was measured as a check against leakage.

Clear BOD bottles containing near-bottom water were incubated 0.5 m above the bottom to estimate dissolved oxygen changes in the water overlying the sediment to separate water column and sediment effects.

## FIELD MEASUREMENTS

Field measurements included temperature, pH, DO, and Secchi depth.

## REFERENCES


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